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On the Relation between Variations of Atmospheric Pressure in North-East Africa and the Nile Flood.

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[PLATE 1.]

Introductory.—The relation of pressure variations to precipitation and the similarity of such variations over wide areas have been studied by several investigators.

In presenting the evidence of variation of climate,* Brückner has shown that in every period of greater rainfall there is a reduction of the differences of atmospheric pressure between stations, while in every dry period there is an increase, and these variations occur both in the differences of pressure between one station and another, and between different seasons.

Sir N. Lockyer and Dr. W. J. Lockyer have discussed periodic variations of pressure in a series of communications to the Royal Society,† wherein they point out that these variations of pressure over the Indian Ocean and neighbouring regions are inverse in character to those which occur in the American area, while certain other regions are intermediate in type.

Dr. F. H. Bigelow has recently dealt with‡ the synchronism of the variations of the solar prominences with terrestial atmospheric pressures, and concludes that "the phenomenon of inversion prevails in the earth's atmosphere, localizing the effect of solar action in two typical curves which are the inverse of one another." The distribution of his direct, indirect, and indifferent types agrees closely with that published by Sir N. Lockyer§ in his paper "On the Behaviour of the Short-Period Atmospheric Pressure Variation over the Earth's Surface."

In 1895, Sir J. Eliot published|| a preliminary discussion of oscillatory changes of pressure in India, and showed that¶ well marked oscillations, having a period of more than a year, occur over the Indian area, and are

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* 'Klimaschwankungen,' Vienna, 1890, p. 218.

† "On some Phenomena which suggest a Short Period of Solar and Meteorological Changes," 'Roy. Soc. Proc.,' vol. 70, p. 501.

‡ 'Monthly Weather Review,' November, 1903, p. 509.

§ 'Roy. Soc. Proc.,' vol. 73, p. 457, 1904.

|| 'Indian Meteorological Memoirs,' vol. 6, Part II.

¶ *Loc. cit.*, p. 117.

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directly related to the character and distribution of precipitation over the Indian monsun area, and to the great atmospheric movements over India. Recently, Professor J. Hann has studied* the relation between the variations of pressure in Iceland and the weather conditions in north-western Europe.

Object of the Present Paper.—The object of the present paper is to show that similar pressure anomalies stand in close relation to the excess or deficit of the monsun rainfall of Abyssinia, and consequently to the Nile flood, which is the direct result of the Abyssinian rainfall. Until recently, the problem has been complicated by the assumption, based on the discharge measurements of Linant de Bellefonds and others, that the volume which the White Nile contributed to the flood was not very greatly inferior to that furnished by the Blue Nile, and consequently the rainfall of the basin of the White Nile and its tributaries must be considered. Now, however, it is known that the volume of the White Nile is held back by the Blue Nile when in flood, and the supply it furnishes is practically negligible until the discharge of the Blue Nile falls below 3000 or 4000 cubic metres per second, that is about October.† It is, therefore, the meteorological conditions on the Abyssinian plateau which determine the rainfall which supplies the whole of the annual flood of the Nile.

A discussion of all available data concerning the Abyssinian rainfall‡ shows that the distribution of rain in the different months of the summer is approximately as follows:—

	June.	July.	August.	September.
North of lat. 9° N....	15 per cent.	30 per cent.	30 per cent.	15 per cent.
South of lat. 9° N....	5 ,,	30 ,,	30 ,,	25 ,,

the remaining 10 per cent. falling in March, April, and May. As the flood wave caused by rainfall in the basin of the Abai or Blue Nile takes from 25 days in July to 15 days in September to reach Aswan,§ we may consider that the meteorological conditions which we have to examine are those of June, July, August, and September, the months of heaviest rainfall on the Abyssinian plateau.

Summer Pressure Anomalies and Flood Conditions.—If the yearly variations from the mean of the atmospheric pressure of the summer months, April to September, are examined (fig. 1), it will be seen that they exhibit an irregular oscillation which is generally inverse to that of the Nile floods; years with high atmospheric pressure correspond closely to those of deficient Nile floods, and those of low atmospheric pressure to the high floods, and consequently with heavier rainfall in Abyssinia. As has been shown by Brückner, Sir N. Lockyer, Bigelow, and others, such oscillations of pressure are to be traced over very wide areas, high or low pressures occurring at nearly the same time in the observations recorded at distant stations. The data which are available for an investigation of the pressure conditions occurring over the Nile basin itself are few, since temperature and rainfall have been more often recorded than atmospheric pressure, for which only a few years' observations in the Nile valley, south of Cairo, and in the Sudan exist as yet; still the observations which are available at Cairo and Alexandria from 1869, and Beirut from 1875, may be utilized to compare the pressure conditions of north-eastern Africa with those of more distant stations.

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* "Die Anomalien der Witterung auf Island in dem Zeitraume 1851 bis 1900 und deren Beziehungen zu den gleichzeitigen Witterungs-anomalien in Nordwest-Europa," 'Sitzungsberichte d. k. Akad. Wiss. in Wien,' 1904.

† Garstin, 'A Report on the Basin of the Upper Nile,' Cairo, 1904; also Blue-book, 'Egypt, No. 3, 1904;' Lyons, 'Geog. Journ.' (not yet printed).

‡ Lyons, 'The Climatography of the Nile Basin,' Survey Dept., Egypt (in the press).

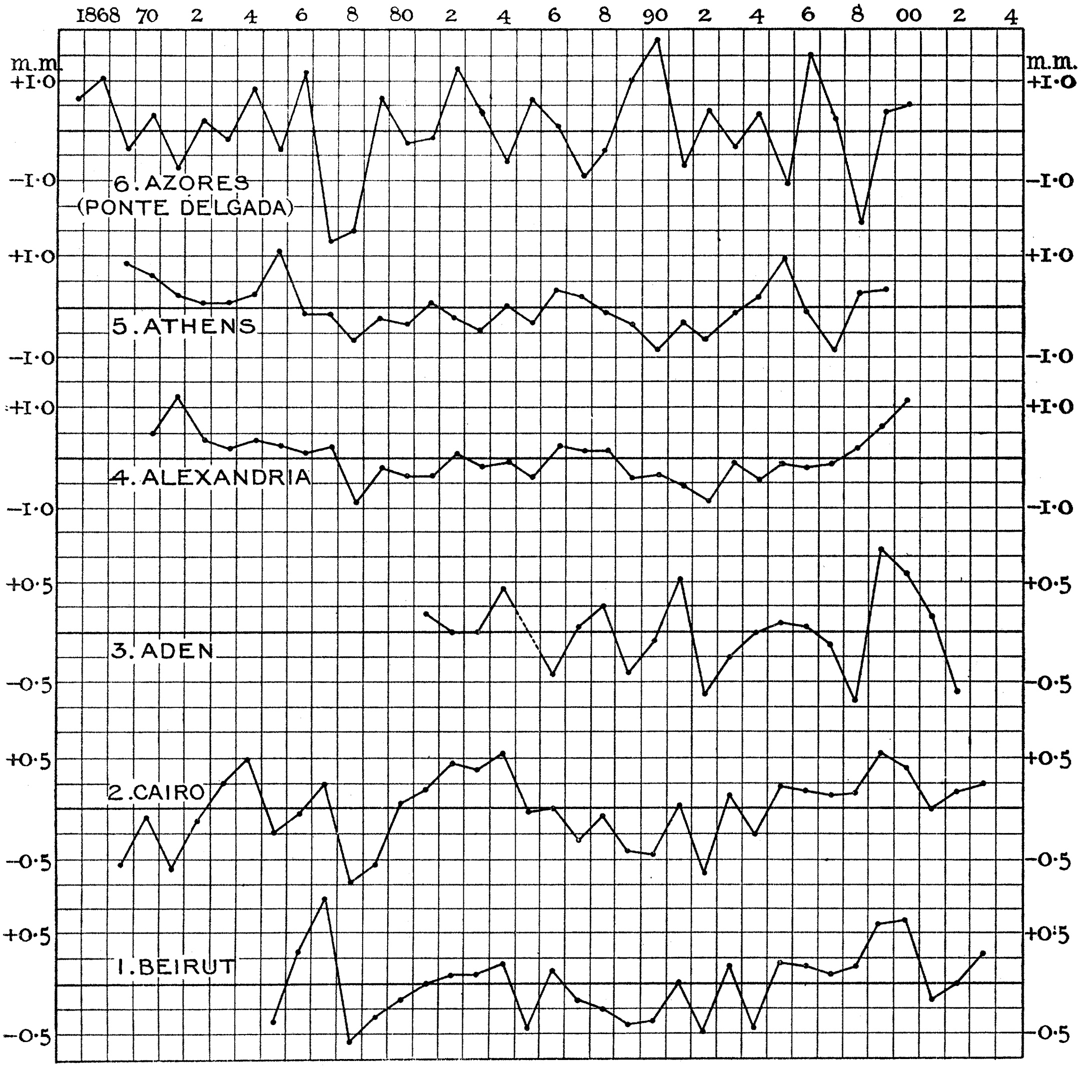
§ Lyons, 'Geog. Journ.'

Taking, now, the summer or low pressure months, April to September, which include the period of rainfall in Abyssinia, the mean value of the barometric pressure is usually above the normal value for these months (as deduced from the 35 years, 1869 to 1903), when the Nile flood is below the average, and below it when the flood is above the average in this series of years (fig. 1); a mean atmospheric pressure for April to September in excess of the normal occurred with twelve low floods as compared with seven high floods, while a deficient mean pressure occurred with fourteen high floods and no low floods.

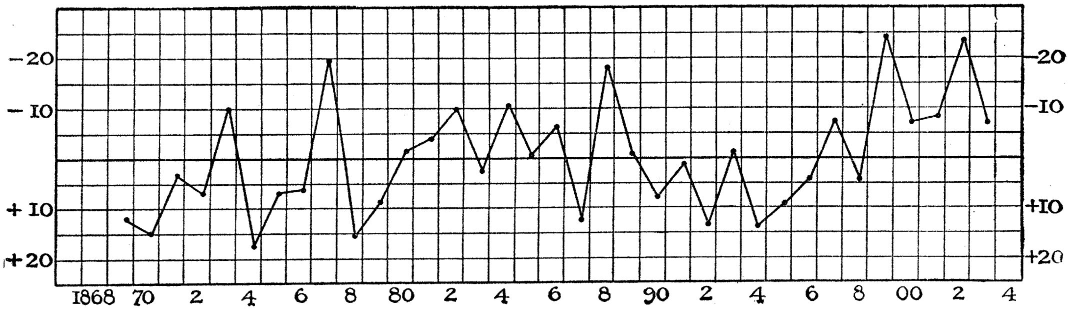
The agreement is more clearly shown if the curves of the mean pressure anomalies and of the Nile floods (inverted) are compared. It will then be seen that not only do excess pressures and deficient floods, and the converse, occur with considerable frequency, but also that the differences from the normal of the two curves, as plotted on fig. 1, show a marked tendency to move in the same direction, although the amount of excess or deficit for any year in the atmospheric pressure may not bear any definite relation to the magnitude of the flood. Of 18 years, in which there was an increase in the mean pressure of April to September, there was a decrease in the flood as compared with the previous year in 16 years and in 2 years there was an increase; in 14 years, in which there was a decrease in the barometric pressure as compared with the previous year, 9 years had an improved flood and 5 years had a worse flood. Therefore, though there is not an exact agreement between the curve of the mean atmospheric pressure for April to

FIG. 1.

Mean Variation of Atmospheric Pressure from Normal for the Months April–September.



Curve (inverted) of Nile Flood.



September at Cairo, and the inverted curve of the Nile floods, there is considerable similarity, which is worth further investigation.

The years in which the agreement is wanting, when the mean summer pressure for April to September and the flood are compared, are :—

	Pressure difference from preceding year.	Pressure difference from normal.	Flood difference in volume from previous year.*	Flood difference from mean.*
	mm.	mm.	Million cubic metres.	Million cubic metres.
1871	−0·49	−0·59	−11,800	+ 3,184
1872	+0·44	−0·15	+ 3,700	+ 6,877
1874	+0·29	+0·55	+27,600	+17,434
1875	−0·79	−0·24	−10,700	+ 6,709
1886	+0·05	+0·01	− 5,320	− 5,855
1901	−0·42	0·00	− 1,500	− 8,661

If the investigation is carried out over a wider field, and the records of barometric pressure of other and more distant stations are utilised, this general agreement is seen to extend to many of them, also showing that variations from the normal pressure occur nearly simultaneously over very large areas.† The variations from the normal pressure have been plotted on Plate 1 for the stations of

Beirut. Zanzibar. Bombay.
Cairo. Mauritius. Hong-Kong.
Aden. Bushire. Shanghai.

Here the general agreement of the maxima and minima are well shown, as well as many of the minor crests, so that it would appear that the barometric conditions, with which a heavy or deficient rainfall in Abyssinia coincides, are often of very wide extension. The agreement of the Cairo pressure curve with the inverted flood curve has been discussed; the Beirut curve has much in common with the Cairo curve but presents some points of interest; the high pressure in 1877 is well marked, coinciding with the very low Nile of that year, as it is in the Bombay and Mauritius curves; at Cairo the discrepancy between the two curves is apparent rather than real, as the pressure was exceptionally high in July and August.

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* The volume of the flood is taken as the volume of water passing Aswan between July 1 and October 31.

† See Lockyer, 'Roy. Soc. Proc.,' vol. 73, p. 457; Bigelow, 'Monthly Weather Review,' November, 1903; Brückner, 'Klimaschwankungen,' Chap. VI, Vienna, 1890; Hann, 'Sitzungsberichte d. k. Akad. d. Wiss. in Wien,' vol. 110, III, January, 1904.

All the curves mark the low pressure of the summer of 1878, a year of high and late flood. In 1879 the pressure was rather higher but agrees with the flood; 1880 continues in the same direction, as also does 1881. In 1882 there are points of peculiar interest to be noted; at Cairo, Beirut, and to a lesser degree at Bushire, the mean pressure increased, and in Egypt the Nile flood was feebler than in any year since 1877, these data being thus in agreement; but in Mauritius, Aden, and Bombay the pressure fell considerably, the Bombay rainfall was in slight deficit, $-1{\cdot}92$ inches, while that for India generally from June to September was 2·1 inches above normal. In 1883 a marked improvement in the flood took place, with a very slight decrease of pressure at Cairo, Beirut, Aden, and rather more at Bushire, but at Bombay it rose. In these two years then Indian and Egyptian pressures and rainfall conditions were not in agreement. In 1884 again the mean pressure increased at most stations and the Nile flood was bad; in 1885 the mean pressure fell at Cairo, Beirut and Aden, it rose at Bushire and Bombay the Nile flood was slightly above the average again, while in Bombay rainfall was 3·1 inches below the average; 1886 shows rather higher pressures at Cairo and Beirut, while the flood was poorer, but Aden, Bushire, and Bombay had lower pressures, and at Bombay there was a large excess of rainfall; in 1887 the conditions were reversed except that in spite of increased pressure Bombay had an excess of rainfall, but the noticeable point is that in these two years again, as in 1882 and 1883, Egypt and Western India are at variance. In 1888, 1889, and 1890 all the curves agree except Aden in the latter year, and the very low flood of 1888 followed by higher ones of 1889 and 1890 are paralleled by the failure of rainfall at Bombay in the first year, and the greatly reduced deficits of the next two years. Until 1894 the curves show satisfactory agreement, but in that year Aden and Bushire contradict the others; in 1895 agreement is again general, but in 1896, 1897, and 1898 the variations of the flood are not well indicated in the Cairo and Beirut curves, and in 1897 Zanzibar alone shows an increased mean pressure.

Pressure Anomalies in the Mediterranean.—In the Mediterranean area the pressure anomalies in summer are generally of the same character as those of Cairo and Beirut, as is shown by the curves of Athens and Palermo, but those of the Azores (Ponte Degada) and Lisbon are usually inverse. It is instructive to notice that in the years 1871, 1874, 1881, and 1882, the Egyptian pressures differ markedly from those of Bombay and India generally, but they agree closely with those of the Azores (see fig. 1), that is with the indirect or Cordoba type of pressure variation, which seems in these years to have extended across northern Africa to Cairo. In 1874 the flood was a very high one, which would not have been anticipated from the high pressure at Cairo, although the pressure fell much in July; possibly conditions to the southward were more favourable than the Mediterranean stations indicate, but no observations are available to bear this out. We find then that Egypt and Abyssinia in their pressure anomalies in the summer months usually agree with the Indian or direct type of pressure, but occasionally revert for a year or two to the opposite type.

Monthly Pressure Anomalies.—So far then, there appears to be considerable probability that the variations of the rainfall in Abyssinia are connected with the variations of barometric pressure from year to year in north-eastern Africa in the summer months, that is from April to September; but it must be remembered that in taking the mean pressure for the six months, April to September, the first two months are unimportant, since practically no rain then falls which appreciably affects the flood, and meteorological conditions in these months may be highly favourable or unfavourable to precipitation without any material effect being produced on the Nile flood, though the mean pressure for the six months is affected by them. It may be to this and to the fact that two or three stations only can furnish observations which are of use in this discussion, that the discrepancies which have been pointed out are due.

When the monthly pressure anomalies at Cairo, Alexandria and Beirut are compared with the monthly excess or defect of the Nile flood as recorded on the Aswan gauge, a closer agreement is found to exist. Sir J. Eliot, F.R.S.,* points out that periodic changes of pressure in India are far smaller in amount than the annual and daily range, take place more gradually, and from their small magnitude accurate and long-continued series of observations are necessary for their discussion. Their importance is not, however, to be measured by their size; Sir J. Eliot is of opinion that in India they are due to the seasonal mass transfer of air across the equatorial belt between Southern Asia and the Indian Ocean and, as a consequence of this, "they are directly related to the largest and most important features of the weather in India, viz., the character and distribution of the precipitation of rain and snow in the Indian monsun area.† It will hardly be remarkable if a somewhat similar oscillation be found to exist in the north-eastern part of Africa, and we may expect it similarly to affect the African monsun rainfall in Abyssinia and the Sudan.

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* 'Indian Meteorological Memoirs,' vol. 6, Part II, Calcutta, 1895.

† *Ibid.*, p. 117.

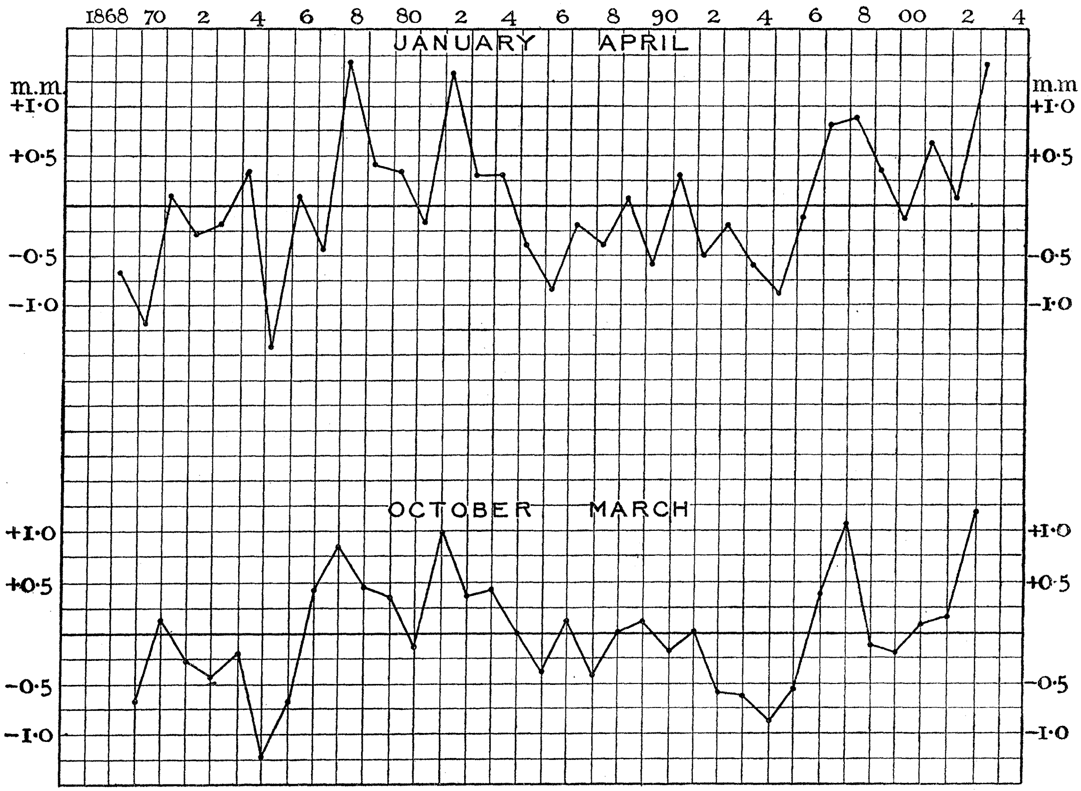
To examine this the "smoothed" values of the differences of mean atmospheric pressure of each month from the normal for Abbassia Observatory, Cairo, have been used. The smoothed values are obtained in the same way as in the Indian Meteorological Memoir already quoted, that is, the smoothed values for any month is the arithmetical mean between the actual values for that month, the preceding and succeeding months. The same has also been done for Beirut, Aden, Zanzibar and Mauritius, and for India, for which the figures have been taken from Sir J. Eliot's Memoir. These smoothed values have been plotted on Plate 1 to a scale of 5 mm. to 1 mm. of variation of pressure from the normal, so that the correspondence between the various stations at the same season can be followed. In the Indian Memoir, (Vol. 6, pt. II) freehand curves have been drawn through the Indian curves; this could easily be done for the Zanzibar curve, but those of Beirut and Cairo are too irregular for a satisfactory curve to be drawn, though traces of oscillations similar to the Zanzibar curve can be traced here and there in them.

In studying these curves, and especially those of Beirut, Cairo, and Aden, we must remember that it is with the effect of the pressure variation during June, July, August, and September that we are principally concerned. This leads to another point; since the rainfall which affects the Nile flood is strictly limited to the Abyssinian area, high and low pressures may occur in the winter months without having any effect on the subject under consideration, the Nile flood. This is the reason that if the mean pressures at Cairo for October to March or even January to April are examined, they show no relation to the variations of the Nile flood (fig. 2).

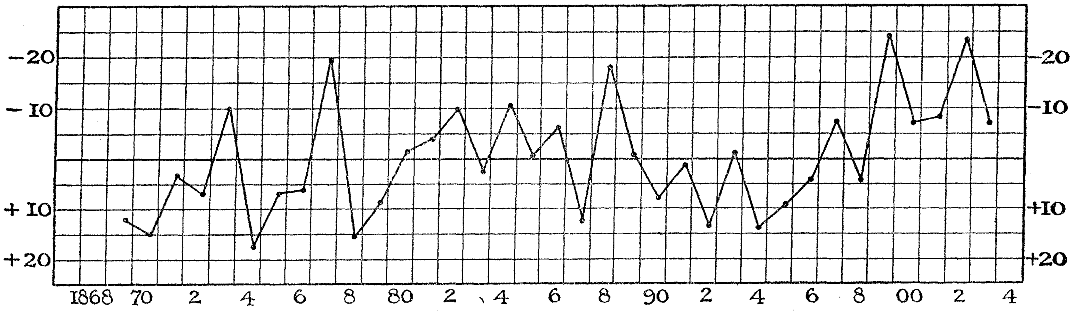
Flood Conditions.—The agreement between the barometric curve for Cairo and the variation of the Abyssinian rainfall and the Nile flood, cannot conveniently be shown graphically when the monthly pressure variations are considered, because the discharge of the Nile in different months depends on different factors. After October the Blue Nile supplies a steadily decreasing amount, until in May its discharge at Khartoum may almost cease; the Sobat is at its maximum in November and decreases until it, too, supplies hardly anything in April in a low year; the combined discharge of the Bahr-el-Zaraf, Bahr-el-Jebel and Bahr-el-Ghazal is always a practically constant amount for the purpose of the present discussion. Although, therefore, pressure conditions might be such in November as to favour a heavy rainfall, and even though this might fall at the equatorial lakes, the Nile discharge would no more be

Fig. 2.

Mean Variation of Atmospheric Pressure from Normal at Cairo.



Curve (inverted) of Nile Flood.



influenced by it than by conditions of excessive drought at a similar time. In short, conditions favourable or unfavourable to precipitation will affect the Nile flood supply in some such way as the following:—

April and May: Advance or retard commencement of flood; June, July, August: Increase or decrease flood; September, October: Delay or accelerate the fall of the flood.

In other months they will have no effect on the Nile supply, since no rain is falling within the effective basin.* The low-stage supply is due to the combined effect of the July to August rainfall, and to the September to October later rains; a heavy rainy season ceasing usually in September, and a moderate rainy season, followed by prolonged September to October rains, may both furnish a good low-stage supply drawn from the stored ground-water and the springs of Abyssinia.

Since the pressure changes are practically simultaneous over wide areas, their effect on the river gauge readings will take place in the flood two to four weeks later at Aswan, according to the distance that the water has to flow, from where the rain was falling to the point of observation, and also on the velocity of the current, while at low stage the discharge is the result of the meteorological conditions in Abyssinia several months earlier. Since, therefore, the pressure curves and river gauge curves cannot be directly compared, Table I, which gives the mean difference of each month's gauge readings from the 32 years' mean of the readings of the Aswan gauge, will be used to show the effect of the rainfall on the river's discharge.

Comparison of Monthly Pressure Anomalies with Excess or Deficiency of Flood.—A comparison of these differences with the pressure anomalies on fig. 1, will serve to show the remarkably close connection which there is in most years between the variations of pressure from the normal at Beirut, Cairo and Aden, and the rainfall of Abyssinia, as represented by the gauge readings at Aswan. In one or two cases even a brief change of pressure for a month appears to be reproduced in the gauge readings, as a consequence of the increased or decreased rainfall, but though no special stress should be laid on these minor agreements, it is certainly remarkable to see how closely the two phenomena of pressure and rainfall agree in most years.

The following table (No. I) gives the monthly mean difference of the Aswan gauge readings from the mean readings of 1872 to 1901, and though these differences do not furnish as accurate a means of comparison as the volume of water discharged in each month would do, still they will not introduce any great error. In Table II the pressure anomalies for June to September are compared with the flood for the year by means of its ratio to a mean flood. This ratio has been obtained by comparing the volume discharged at Aswan between July 1 and October 31 in each year.

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* Strictly speaking, Wadelai on the Bahr-el-Jebel (lat. 3° N.), which has November rains, would be within the effective basin, since there is a direct waterway from this point to the lower reaches of the Nile, but as the discharge at the mouth of this river, where it joins the White Nile, only varies between 250 and 350 cubic metres per second throughout the year, this rainfall has no seasonal effect on the Aswan discharges.

The nine years which disagree may now be examined more in detail.

In 1874, pressure at Cairo was much above the normal in March, April, and May, after which it fell rapidly till the end of the year; the flood at Aswan was in considerable excess from the middle of June onwards.

In 1876, though Cairo pressure was above the normal, that of Beirut and Alexandria was below it.

Table I.—Mean Difference of Gauge Readings at Aswan in Centimetres from the Mean Gauge Readings of 1872 to 1901.

Year.	July.	Aug.	Sept.	Oct.	Year.	July.	Aug.	Sept.	Oct.
1869	+ 46*	+ 39	+ 61	+115	1887	+ 79	+122	+ 77	+ 14
1870	+ 71	+108	+ 53	+ 95	1888	− 82	− 74	−106	−146
1871	+ 32	+ 57	+ 22	+ 1	1889	− 61	+ 14	+ 23	+ 4
1872	+ 88	+ 42	+ 34	+ 78	1890	− 13	+ 74	+ 46	+ 80
1873	+ 18	− 58	− 48	− 54	1891	− 5	+ 6	+ 15	+ 48
1874	+ 76	+124	+ 94	+ 83	1892	− 30	+ 40	+ 99	+121
1875	+ 13	+ 58	+ 36	+ 64	1893	− 54	+ 20	− 22	+ 51
1876	+ 93	+ 42	+ 63	+ 11	1894	+ 65	+ 72	+ 68	+131
1877	+ 47	−107	−154	−122	1895	+ 62	+144	+ 41	+ 1
1878	− 24	+ 10	+ 95	+182	1896	+ 38	+ 2	+ 53	+ 29
1879	+168	+ 72	+ 44	+ 42	1897	+ 2	− 56	− 16	− 26
1880	+122	+ 27	− 24	− 18	1898	− 47	+ 42	+ 42	+ 55
1881	− 44	− 78	+ 28	+ 2	1899	− 52	−144	−152	−194
1882	− 92	− 80	− 34	− 45	1900	−105	− 17	− 55	− 41
1883	+ 43	+ 55	+ 22	− 3	1901	− 30	− 16	− 23	−105
1884	− 45	− 75	− 62	− 10	1902	−120	−249	−127	− 79
1885	+ 78	+ 66	− 28	− 39	1903	− 49	−118	− 18	+ 10
1886	− 38	− 12	− 2	− 41					

In 1883, pressure was above the normal until October, the maximum being in July; the flood was in moderate excess July to September, with a considerabe excess July 25 to August 10; October in moderate defect.

In 1888, pressure at Cairo was below normal till August, then above it; Beirut was below normal, but rising; at Aden it was high in September. The flood of July and August was in considerable defect, and after September 15 in large defect.

In 1891 pressure at Cairo was below normal April to June, and above it July to September; pressure at Aden fell steadily after July. The flood was in good excess June 10 to July 5, moderate defect July 15 to August 10, normal July 20 to September 30, moderate excess in October.

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* Ten days only.

In 1893, pressure at Cairo was high in March, April, and May, after which it fell to slightly below normal; at Beirut July was above normal, after which pressure fell; at Aden pressure rose in August. The flood was in defect in June and July; in fair to good excess in August; in moderate defect in September.

In 1895 pressure at Cairo was high in April to June, after which it fell steadily, being normal in August; at Aden it was low after June. The flood was in good excess June to September, and in large excess August 1 to 25.

Table II.—Comparison of Pressure Anomalies, June to September, at Cairo, with the Ratios of the Nile Floods to a Mean Flood.

Year.	Ratio to mean flood.	Pressure anomaly.*	Year.	Ratio to mean flood.	Pressure anomaly.*
		mm.			mm.
1869	1·18	−0·67	1887	1·19	−0·47
1870	1·23	−0·12	1888	0·72	−0·06†
1871	1·05	−0·49	1889	1·00	−0·45
1872	1·11	−0·49	1890	1·12	−0·28
1873	0·84	+0·43	1891	1·01	+0·42†
1874	1·26	+0·36†	1892	1·20	−0·52
1875	1·10	−0·14	1893	0·99	−0·22†
1876	1·09	+0·16†	1894	1·22	−0·38
1877	0·70	+0·91	1895	1·15	+0·33†
1878	1·25	−0·86	1896	1·06	+0·09†
1879	1·14	−1·15	1897	0·89	+0·06
1880	0·98	+0·11	1898	1·07	−0·005
1881	0·93	+0·11	1899	0·63	+0·54
1882	0·84	+0·60	1900	0·89	+0·30
1883	1·04	+0·39†	1901	0·87	−0·09†
1884	0·83	+0·95	1902	0·63	+0·11
1885	0·99	+0·02	1903	0·89	+0·30
1886	0·91	+0·17			

In 1896, pressure at Cairo was high June to August, and low in September; at Aden generally low but above normal in August. The flood was in small excess in June, moderate excess in July, considerable defect in August, and good excess in September.

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* Mean of the mean anomalies of the months June, July, August, September.

† Years in apparent disagreement from the rule that − anomalies coincide with floods above the average, and + anomalies with floods below the average.

In 1901, pressure at Cairo was high till May, then fell to just below normal; Aden and Zanzibar were above normal. The flood was in moderate defect until the end of September, except for a moderate excess from August 15 to 31; in October there was a large defect.

Out of these nine years then, 1883 and 1895 floods alone are in disagreement, while those of 1874 and 1896 are in fair agreement only, though it should be said that the years of 1888 and 1902 were not so remarkable for conditions of high pressure as the deficiency of rainfall would have led one to expect.

Percentage of Agreement.—Still we may say that 30 out of the 35 years, or 86 per cent., show a good agreement of − anomalies of pressure with excess of rainfall and + anomalies with a deficiency, which is sufficiently satisfactory to encourage further study; it at all events furnishes a working hypothesis which may be used to estimate the probability of a year's flood being much below or above the normal, and as knowledge advances a closer estimate may perhaps be formed.

Extent of Agreement with the South-west Monsun of India.—As the Abyssinian rains are due to the monsun of Eastern Africa, which in the summer months crosses the equator and extends as southerly and south-westerly moisture-laden winds as far as Khartoum (lat. 15° 40′ N.), and even to Suakin (lat. 19° N.), it is not surprising that there should often be considerable similarity between the Abyssinian rainfall and the south-west monsun of India. The relation is not, however, so close as Sir W. Willcocks* and Sir John Eliot† have maintained; years of famine or excessive rain in India usually coincide with low or high Nile floods as might be expected, since conditions unfavourable or favourable to precipitation will be strongly marked and consequently wide in their influence,‡ but if the series of years, 1875 to 1903, is taken, 9 years§ out of 27 are in disagreement, as may be seen from the following table. If the Bombay rainfall is taken, the result is even less satisfactory. Therefore, in basing anticipations of the Nile flood solely on the prospects of the Indian south-west monsun, it would seem likely that as many times as 1 in 3 they would not be fulfilled, a very much lower proportion than the 1 in 7, derived from the barometric anomalies of Beirut, Cairo, and Aden.

Low Stage of Nile.—Besides the heavy rains of July and August which

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* A paper read before Meteor. Congress, Chicago.

† 'Nature,' August 23, 1900, p. 392.

‡ Lyons, 'Geog. Journ.'

§ *I.e.*, 1876, 1881, 1882, 1883, 1884, 1886, 1891, 1896.

Table III.

Year.	Ratio of Nile flood to mean flood.	Indian rainfall.* Year variation from normal.		Bombay rainfall.† Variation from normal. April to September.
		Year.	June to Sept.	
		in.	in.	in.
1875	1·11	+2·38	?	+13·08
1876	1·10	−4·49	−3·4	−21·00
1877	0·71	−4·28	−9·3	+ 1·40
1878	1·25	+6·34	+2·9	+41·71
1879	1·15	+1·69	+2·7	− 9·64
1880	0·99	−1·56	−2·6	− 3·10
1881	0·64	+0·10	+2·4	+ 1·99
1882	0·65	+2·64	+2·1	− 1·92
1883	1·05	−0·12	−1·7	+19·05
1884	0·84	+1·73	+2·5	+ 3·26
1885	1·00	+1·05	+0·8	− 3·10
1886	0·92	+3·02	+1·4	+28·72
1887	1·21	+2·42	+0·1	+23·76
1888	0·72	−1·54	+0·6	−15·16
1889	1·00	+2·41	+3·3	− 3·26
1890	1·13	+0·68	+1·3	− 5·97
			June to Dec.	
1891	1·02	−3·54	−4·25	+ 5·94
1892	1·21	+5·09	+5·69	+24·10
1893	1·00	+9·07	+4·72	− 4·13
1894	1·23	+6·47	+6·75	− 4·46
1895	1·16	−2·90	−1·95	− 3·49
1896	1·08	−4·83	−3·59	+16·63
1897	0·90	−0·15	−0·02	+10·51
1898	1·07	+0·43	+0·93	+ 2·91
1899	0·63	−11·14	−11·34	−36·68
1900	0·90	−0·57	−0·26	− 1·87
1901	0·88	−4·13	−5·12	
1902	0·64	−2·05	−1·64	
1903	0·89			

principally supply the Nile flood, the meteorological phenomena may also indicate conditions favourable or unfavourable to precipitation at the time of the later autumn rains of September and October which affect the low stage or summer supply of the river.

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[*] Eliot, 1875 to 1896, see 'Nature,' June 3, 1897, p. 110; 1897 to 1902, see 'Nature,' August 25, 1904, p. 403.

[†] 'Indian Meteorological Memoirs.'

The connection is not so simple as in the case of the flood, for the effect of heavy autumn rains may be counteracted by the effects of a very deficient rainfall of earlier months, while an unusually copious rainfall will give a good low stage supply, even though the autumn rains have been feeble.

In Table IV the pressure anomalies for September and October are compared with the mean excess or defect of the March to May gauge readings at Aswan of the following year. From this it is seen that out of 34 years a negative value of the mean of the anomalies for September and October was followed by a low stage above the average, and a positive value by one below the average in seventeen cases.

If now we take the excessively high floods of 1870 and 1878, when the summer rains were sufficiently heavy to mask any effect of the positive pressure anomalies in the autumn, and also the very low floods of 1873, 1877, 1888, 1901 and 1902, when deficient summer rainfall outweighed the precipitation which we may assume accompanied the small negative pressure anomalies of the autumn, the cases which agree with what might be expected are 24 out of 34, or 71 per cent.; of the 11 discrepant years, 1871 and 1891, which were followed by a deficient low-stage supply, and 1883, which was followed by a favourable low stage, had respectively + and − pressure anomalies in September, which month would naturally be more effective in rainfall than October.

This agreement is as good a one as can be expected where so many causes are at work, and where no data from the immediate neighbourhood are available.

It should be mentioned here that the true distribution of pressure in Egypt and the Sudan is very different from that usually shown in meteorological atlases.* In April and May the principal feature is a low-pressure area which lies over Abyssinia and the Eastern Sudan, and to which the early rains (Azmera) of Abyssinia are due; by June it has joined the trough of low pressure which extends across Beluchistan in a south-westerly direction, and a gradient exists everywhere from the Nile Valley towards the neighbourhood of Muskat and Bushire. In July this gradient is steepest; in August it is somewhat reduced by a slight rise of pressure in the Persian Gulf, and is very considerably reduced in September. Thus instead of a continuous trough of low pressure extending from Central Asia into the central part of North Africa, there is a marked gradient† eastwards

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* This distribution of pressure is discussed in a Report on the Climatography of the Nile Basin which will be published shortly.

† Five millimetres in about 8° of longitude between Dueim, lat. 14° N. on the White Nile, and the Red Sea in July.

Table IV.

Year.	Pressure variation.			Flood ratio to mean flood.	Mean difference from mean gauge readings at Aswan, of March, April, May, next year.
	September.	October.	Mean.		
	mm.	mm.	mm.		cm.
1869	−1·16	+0·75	−0·20	1·18	—
1870	+0·04	+0·15	+0·10	1·23	+ 39
1871	+0·34	−0·65	−0·16	1·05	− 52
1872	+0·34	+0·15	+0·25	1·11	− 2
1873	−0·36	+0·05	−0·16	0·84	− 79
1874	+0·44	+0·35	+0·40	1·26	− 4
1875	+0·84	−3·05	−1·10	1·10	+ 39
1876	+0·34	+0·45	+0·40	1·09	− 4
1877	−0·26	−0·45	−0·36	0·70	− 74
1878	−0·38	+0·47	+0·05	1·24	+177
1879	−1·11	+0·52	−0·28	1·14	+110
1880	+0·14	+0·27	+0·20	0·98	− 6
1881	−0·03	+0·06	+0·02	0·93	− 35
1882	+0·38	+0·37	+0·38	0·84	+ 20
1883	−0·45	+0·68	+0·12	1·04	+ 58
1884	+0·98	+0·68	+0·83	0·83	− 25
1885	+0·08	+0·19	+0·14	0·99	− 26
1886	−0·11	−0·52	−0·32	0·91	− 21
1887	−0·21	−0·58	−0·40	1·19	− 10
1888	+0·42	−0·45	−0·02	0·72	− 82
1889	−0·28	+0·25	−0·02	1·00	− 67
1890	+1·44	+0·97	+1·20	1·12	− 32
1891	+0·68	−0·77	−0·04	1·01	− 48
1892	−0·80	−0·61	−0·70	1·20	+123
1893	−0·68	−0·25	−0·46	0·99	− 15
1894	−0·40	+0·27	−0·06	1·22	+104
1895	+0·92	−0·87	+0·02	1·15	+ 58
1896	−0·54	−0·02	−0·28	1·06	+ 66
1897	−0·17	+0·92	+0·38	0·89	− 25
1898	−0·17	−1·30	−0·74	1·07	−129
1899	+0·11	+0·31	+0·21	0·63	+ 72
1900	+0·69	+0·28	+0·48	0·89	− 61
1901	−0·07	−0·18	−0·12	0·87	− 76
1902	−0·39	+0·30	−0·05	0·63	− 85

from about the line of the Nile Valley. Here the isobars run from N.N.W. to S.S.E. as far as about lat. 10° N., when they turn E.S.E.

The last few years have shown that the rainfall on the Bahr-el-Jebel, lat. 2° N. to lat. 7° N., may differ entirely from that of Abyssinia in its character, but the causes of this are still unknown. In 1878 and 1879 the rainfall was exceptionally heavy in both areas; in 1899 it was extremely deficient in both; on the other hand, while 1902 and 1903 were years of very deficient and slightly deficient rainfall in Abyssinia, the fall in the districts to the north of Lake Albert was very heavy and exceptionally heavy respectively.

Possibility of Flood Prediction.—The present hypothesis seems to furnish us with a more satisfactory basis for predicting the character of the Nile floods when it is used in conjunction with the indications of the Indian south-west monsun, as they are construed by the Meteorological Department of India, than most of the proposals which have been previously made.

Mahmud Pasha El Falaki, in a paper* read before the Khedivial Geographical Society at Cairo, January 6, 1882, suggested that the Nile flood might be predicted by a study of the temperatures and barometric pressures observed at Cairo, and as he was under the impression that the White Nile furnished a considerable part of the flood, he proposed to consider the meteorological conditions in February, March, and April as furnishing a guide to the probability of an excess or deficit of equatorial rainfall, and those of July as indicating the conditions on the Abyssinian plateau. Having taken the spring months, he was led to consider that a high temperature and a low pressure coincided with the low flood, and a low temperature and high pressure with a high flood, basing his view on the years 1870 to 1881.

Ventre Pasha,† in a paper on the hydrology of the Nile, discusses the possibility of predicting the flood, and concludes that the knowledge of the force and direction of the winds in the neighbourhood of Aden and Zanzibar should furnish a basis for satisfactory forecasting. He refers to some investigators who have endeavoured to trace a connection between the Nile flood and the barometric pressure and temperature at Cairo, but that such a relation is possible he denies, apparently on the ground that the distance between the equatorial lakes and Cairo is over 3500 kilometres, and consequently too great for meteorological phenomena at the two places to have any relation to one another; but it is with the Abyssinian plateau some 2200 kilometres distant that we have to do, and also variations of barometric pressure are frequently found to occur over as great and even greater areas.

Ventre Pasha also speaks of what he considers to be a law,‡ viz., that a low flood is followed by a low summer supply, but this is only a natural sequence, since a low flood means insufficient rainfall on the Abyssinian area, and consequently the September rains are likely to be also below the average. Therefore the springs and streams will run low or dry sooner than in wetter years, and the Sobat and Blue Nile, the two variable factors of the summer or low-stage supply, will be furnishing but little. On the other hand, it will sometimes occur that a season of deficient rainfall may improve towards the end, as was the case in 1903, when the increased rainfall in the autumn provided a good low-stage supply for 1904.

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* 'Bull. Soc. Khéd. Géog.,' February 6, 1885, p. 327.

† 'Bull. Soc. Khéd. Géog.,' January, 1894, Cairo.

‡ 'Bull. Soc. Géog. Cairo,' January, 1894, p. 41.

It is, therefore, rather on the amount of rain falling at the end of the rainy season in Abyssinia, and its continuance into the autumn months, that a good low-stage supply depends; the Sobat keeps up the level of the White Nile with the water it brings from the high lands of Kaffa, and the Blue Nile is fed by its tributaries in Gojam and Wallega. In 1903, the Blue Nile was discharging nothing at Khartoum on the 8th, 15th, and 23rd of May, after the deficient rainfall of 1902.

Sir W. Willcocks,* in his paper on the Wadi Rayan, refers incidentally to the prediction of the Nile floods, and considers that good floods coincide with high humidity in June, and with a prevalence of southerly winds in April and May at Cairo; also that deficient floods are heralded by exceptional dryness in June and few southerly winds in April and May.

In the 33 years—1870 to 1902—the mean relative humidity in June is not of any real value as a guide in prediction, since out of 19 years in which the relative humidity in June was above the mean, 9 floods were below the average, and 10 were above it; and of 13 years in which the humidity was below the mean, 8 floods were above the average, and 5 were below it.

Turning now to the southerly winds, the number of observed winds of which the direction was south of east or west (from some part, that is, of the southern half of the horizon) has been taken from the 3-hourly observations at Abbassia (near Cairo). In 9 years, when the flood was above the average, the southerly winds were above the average in 5 years, and below it in 4 years. In 7 years having floods *below* the average the southerly winds were below the average in 4 years and above it in 3 years.

It cannot therefore be said that either the mean relative humidity in June or the prevalence of southerly winds in April and May are safe guides in predicting the Nile flood; the proposed relation will be found to hold occasionally, as in 1902, when there were few southerly winds and a large deficiency in the flood, also in 1892 was a high Nile, and the June relative humidity was also high, but in no sense can they be considered as satisfactory bases for regular prediction. Sir W. Willcocks does not say what he considers the relation between these phenomena, and the precipitation in Abyssinia to be; no relation of cause and effect is indicated, nor are they shown to be effects of the same cause.

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* 'The Aswan Reservoir and Lake Moeris,' London, 1904; and 'Khéd. Géog. Soc.,' January, 1904.

It seems that the two principal factors to be considered are firstly the strength of the south-east trade winds as they progress from the south to the north of the equator, along the eastern coast of Africa, and secondly, the excess or defect of atmospheric pressure in the area represented by Aden, Cairo, Beirut, and careful study, year by year, of the varying conditions, will be necessary before their effects are properly understood.

The results may be summarised as follows:—

1. Generally speaking the curve of Nile floods varies inversely as the mean barometric pressure of the summer months, high pressures accompany low floods, and low pressures accompany high floods.

2. These pressure variations show a great similarity over wide areas, from Beirut to Mauritius, and from Cairo to Hong-Kong, and are usually of Sir N. Lockyer's Indian type of curve, or Professor Bigelow's "direct" type.

3. Occasionally, however, pressure at Beirut and Cairo is in disagreement with that of the rest of the area, and then more nearly approaches the "Cordoba" type of Sir N. Lockyer, or the "indirect" type of Professor Bigelow. This would seem to be a confirmation of other evidence which tends to show that Egypt belongs to the class of Brückner's "temporarily exceptional" areas.

4. Taking the monthly means of atmospheric pressure, this relation is even more clearly shown, and pressure above or below the normal in months of the rainy season of Abyssinia coincides closely with deficiency or excess of rainfall.

5. Taking the 35 years—1869 to 1903—in 6 years out of 7 a very fairly accurate prediction of the flood from month to month could have been made.

Conditions in 1904. The data which have been utilised extend up to 1902 or 1903; 1904 may be examined to see what amount of accuracy would have been arrived at. In the early summer of the present year it was the general opinion in Egypt that there would be a good Nile flood, and Sir W. Willcocks wrote,* "Egypt has had a very good supply this year . . . . the Atbara and the other rivers are coming down fairly early, so that all anxiety about

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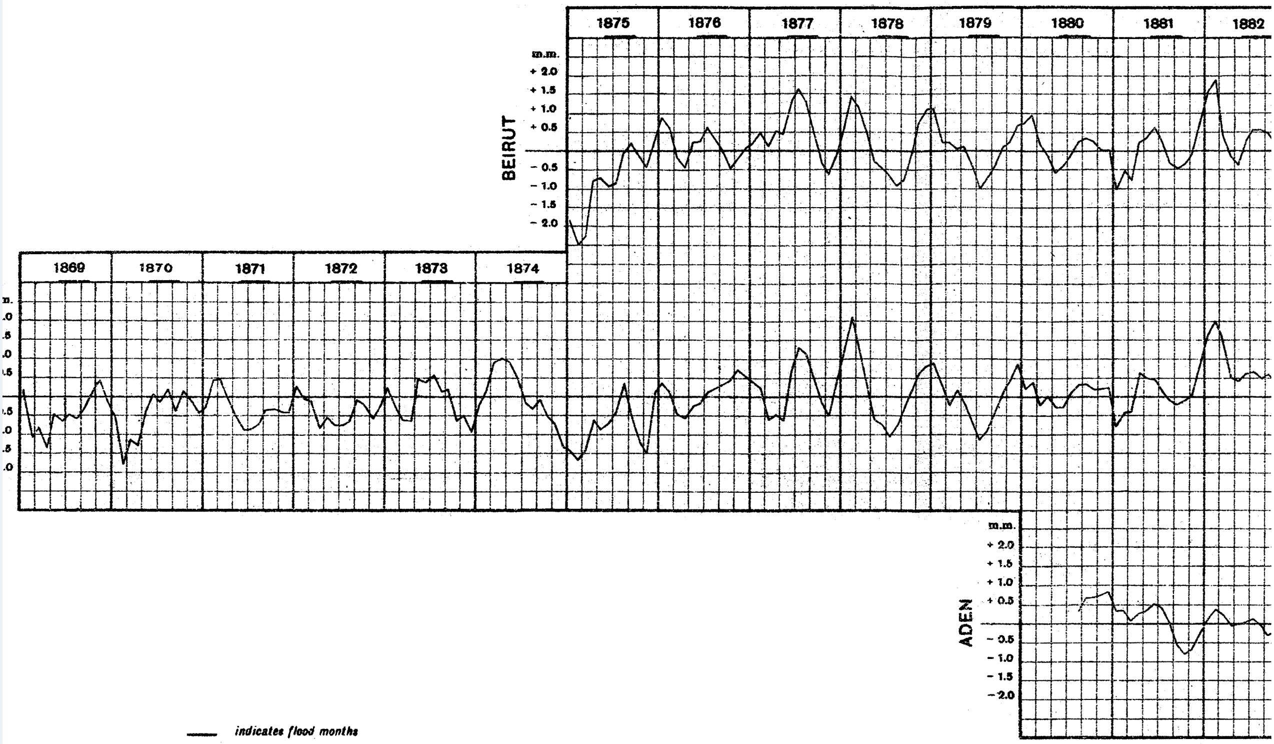
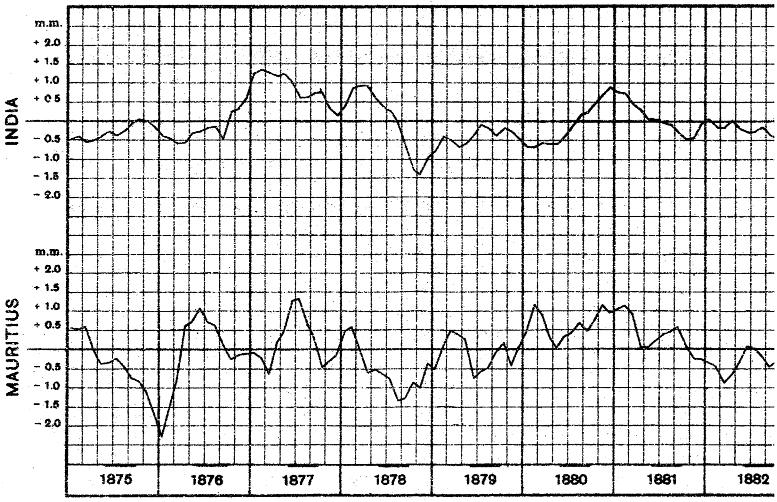
* 'Egyptian Gazette,' June 11, 1904.

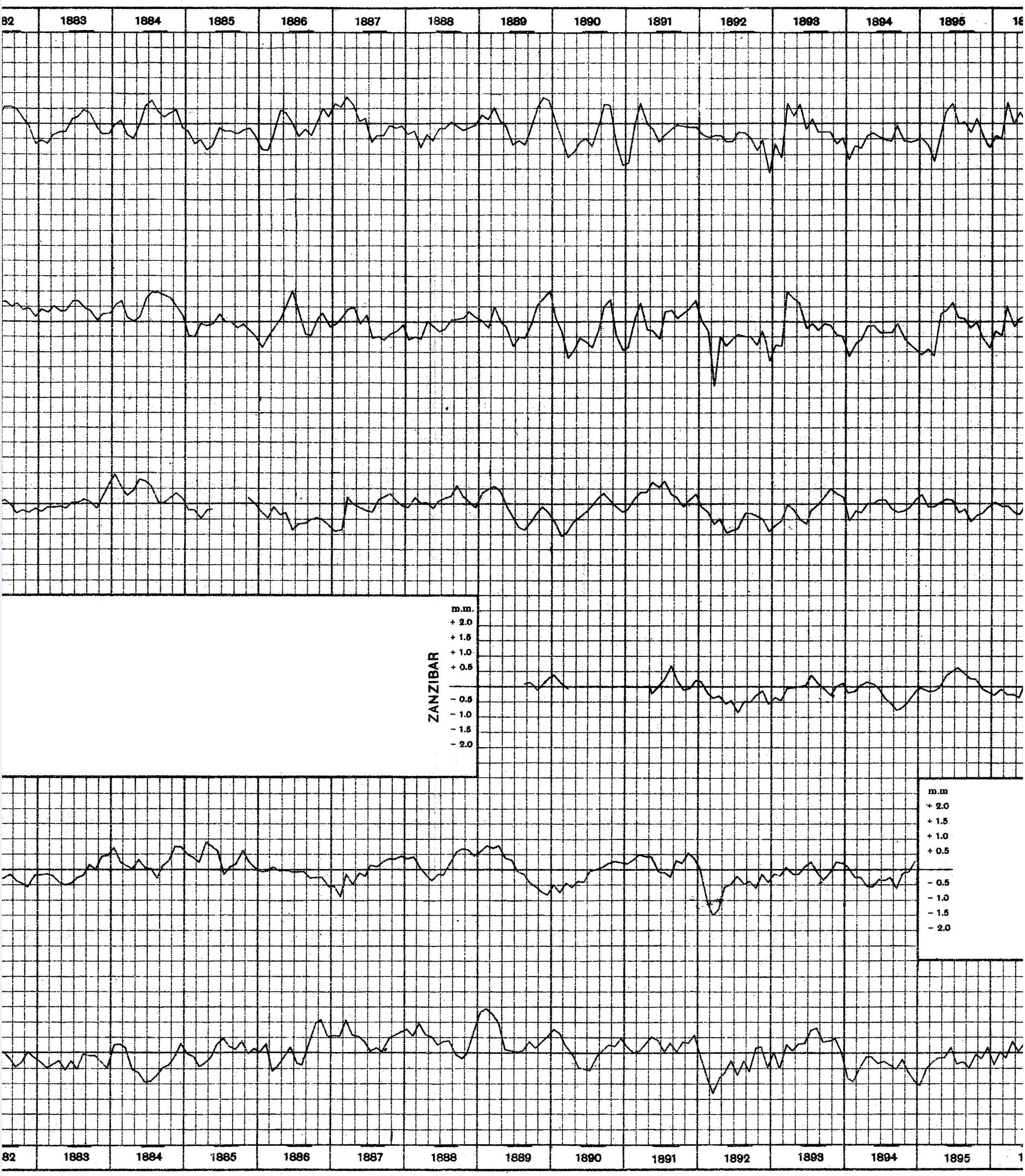
ATMOSPHERIC

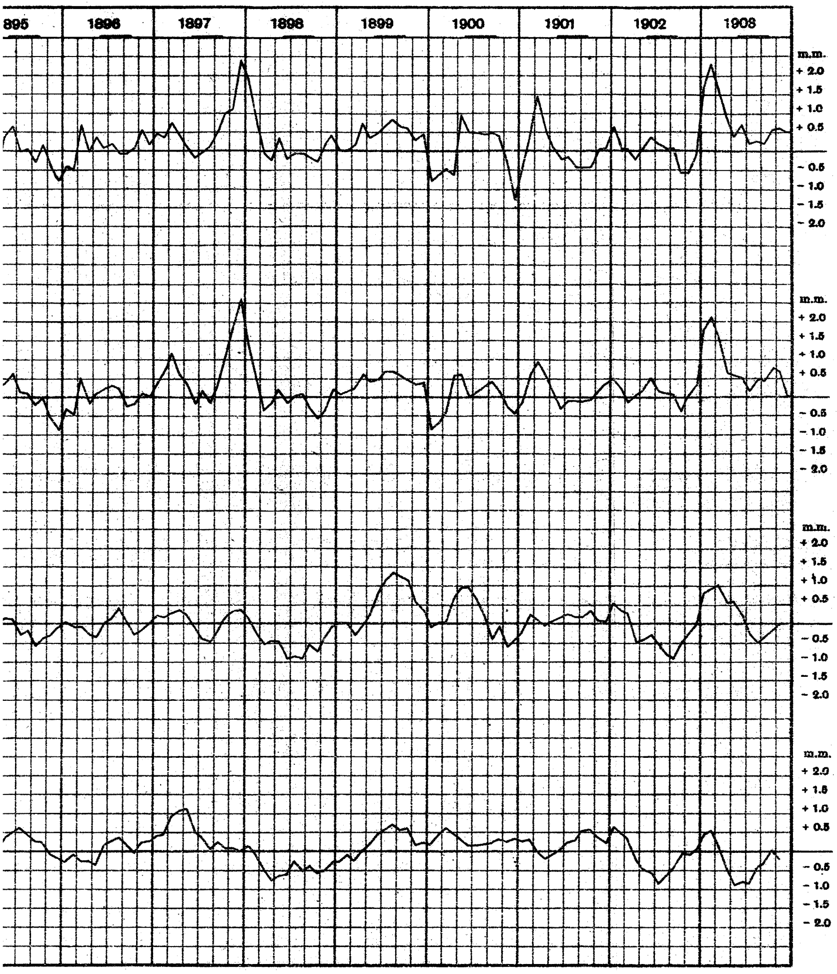




C PRESSURE: DIFFERENCES FROM THE NORMAL MONTHLY VALUES.

Scale, 5 millimetres to 1 millimetre of the Barometric Scale

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1896
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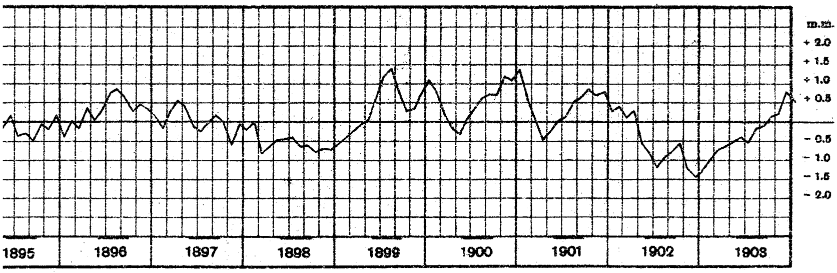
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want of water may be dismissed for 12 months"; yet the flood of 1904 was a low one, and the low-stage supply promises to be exceptionally low. Looking at the meteorological data, at no time after April was there any evidence that the Abyssinian rainfall was likely to be heavy.

The following Table V shows that in Northern Egypt and Arabia pressure was in excess in April and May, and in June all stations show the same; by this time the slight deficiency in the river level at Wadi Halfa* in April and May had disappeared, but the high pressure in June rendered it improbable that the rainfall of that month in Abyssinia, which would affect the Nile at Wadi Halfa in July, would be above the average. In July, conditions were more favourable, and rains were plentiful, but in August, high pressure again set it, and in Abyssinia rains were very scanty, so that the mean level of the river at Wadi Halfa, was 83 cm. below the average in September.

In Table VI the mean 10-day readings of Roseires and Khartoum on the Blue Nile, and of Khashm-el-Girba and Berber for the Atbara, are given for 1903 and 1904. These show clearly that in June the river was low and rising slowly until the last week of June, when the level rose markedly, and this continued throughout July, until the beginning of August; then a rapid fall took place as the rains weakened in consequence of the unfavourable high pressure conditions, and as these continued throughout the month, it soon became clear that the flood would be a feeble one.

Table V.—Monthly Pressure Anomalies, 1904.

Place.	March.	April.	May.	June.	July.	Aug.	Sept.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Beirut	−1·00	+0·30	+0·50	+0·33	+0·73	+0·66	+1·06
Alexandria	−1·00	+0·10	+1·00	−0·10	−0·70	+0·40	+0·70
†Aden	−0·80	−0·60	−0·30	+0·93	−0·23	+0·50	+0·88
Zanzibar	−0·43	0	−0·35	+0·66	−0·23	+0·45	+1·22
†Bushire	−0·70	+0·10	+0·80	+0·35	−0·45	−1·00	+0·82
†Muscat	−0·35	−0·65	−0·55	+0·23	−0·58	+0·23	+0·70
†Kurachi	−0·30	−0·93	−0·73	+0·15	+0·08	+0·20	+1·80
Mauritius	−1·23	−0·10	+0·15	+1·55	+0·05		
	Difference from mean of 1891 to 1902 in centimetres.						
Wadi Halfa Nile gauge	−17	−18	−7	0	−25	−42	−83

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* The Aswan cannot be used, as in these months the reservoir is supplying water.

† After April taken from Daily Weather Reports.

Table VI.

	Roseires.			Khartoum.			Khashm-el-Girba.			Berber.		
	1903.	1904.	Diff.	1903.	1904.	Diff.	1903.	1904.	Diff.	1903.	1904.	Diff.
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
May 1—10	−0 ·49	−0 ·26	+0 ·23	−0 ·23	0 ·12	+0 ·35	—	—	—	0 ·78	1 ·08	+0 ·30
„ 11—20	0 ·08	0 ·06	−0 ·02	0 ·24	0 ·15	+0 ·39	—	—	—	0 ·78	1 ·00	+0 ·22
„ 21—31	1 ·72	0 ·92	−0 ·80	0 ·39	0 ·38	−0 ·01	—	—	—	0 ·92	1 ·13	+0 ·21
June 1—10	2 ·03	1 ·49	−0 ·54	1 ·19	0 ·89	−0 ·30	10 ·94	9 ·83	−1 ·11	1 ·75	1 ·48	−0 ·27
„ 11—20	2 ·12	1 ·27	−0 ·85	1 ·65	1 ·11	−0 ·54	11 ·21	10 ·40	−0 ·81	2 ·27	1 ·98	−0 ·29
„ 21—30	2 ·10	2 ·46	+0 ·36	1 ·58	1 ·08	−0 ·50	12 ·05	11 ·12	−0 ·93	2 ·71	1 ·91	−0 ·80
July 1—10	3 ·18	3 ·65	+0 ·47	2 ·02	2 ·29	+0 ·27	12 ·32	12 ·23	−0 ·09	3 ·05	2 ·64	−0 ·41
„ 11—20	3 ·96	4 ·42	+0 ·46	2 ·75	3 ·27	+0 ·52	12 ·41	13 ·00	+0 ·59	3 ·81	4 ·24	+0 ·43
„ 21—31	4 ·80	6 ·02	+1 ·22	3 ·37	4 ·18	+0 ·81	12 ·85	13 ·50	+0 ·65	4 ·55	5 ·39	+0 ·84
August 1—10	7 ·27	7 ·52	+0 ·25	4 ·50	5 ·48	+0 ·98	13 ·52	13 ·86	+0 ·34	5 ·74	6 ·68	+0 ·94
„ 11—20	8 ·42	6 ·08	−2 ·34	5 ·60	5 ·37	−0 ·23	14 ·94	13 ·01	−1 ·93	7 ·20	6 ·61	−0 ·59
„ 21—31	8 ·29	6 ·55	−1 ·74	6 ·06	5 ·39	−0 ·67	14 ·69	13 ·07	−1 ·62	7 ·72	6 ·56	−1 ·16
September 1—10	7 ·88	6 ·42	−1 ·46	6 ·19	5 ·48	−0 ·71	14 ·51	12 ·98	−1 ·53	7 ·74	6 ·79	−0 ·95
„ 11—20	7 ·24	6 ·38	−0 ·86	5 ·94	5 ·38	−0 ·56	13 ·98	12 ·58	−1 ·40	7 ·48	6 ·73	−0 ·75
„ 21—30	6 ·85	5 ·24	−1 ·61	5 ·50	5 ·00	−0 ·50	13 ·25	11 ·84	−1 ·41	7 ·36	6 ·34	−1 ·02

With weak summer rains and high pressure conditions in September and the first part of October, no large amount of water can have been stored up in the soil of Abyssinia, so that the springs will run off early, and a very low stage may be expected in 1905.

ATMOSPHERIC PRESSURE: DIFFERENCES FROM THE NORMAL MONTHLY VALUES.

Scale, 5 millimetres to 1 millimetre of the Barometric Scale